

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
13 December 2001 (13.12.2001)

PCT

(10) International Publication Number
WO 01/95666 A2

(51) International Patent Classification⁷: H04R 3/00

(21) International Application Number: PCT/SG00/00080

(22) International Filing Date: 5 June 2000 (05.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US):
NANYANG TECHNOLOGICAL UNIVERSITY
[SG/SG]; Centre for Signal Processing, School of Electrical & Electronic Engineering, Block S2, Level B4, S2-B4b-05, 50 Nanyang Avenue, Singapore 639798 (SG).

(72) Inventors; and

(75) Inventors/Applicants (for US only): ZHANG, Ming
[CN/SG]; Centre for Signal Processing, School of Electrical & Electronic Engineering, Block S2, Level B4, S2-B4b-05, 50 Nanyang Avenue, Singapore 639798 (SG). LAN, Hui [CN/SG]; Centre for Signal Processing, School of Electrical & Electronic Engineering, Block S2, Level

B4, S2-B4b-05, 50 Nanyang Avenue, Singapore 639798 (SG). SER, Wee [SG/SG]; Centre for Signal Processing, School of Electrical & Electronic Engineering, Block S2, Level B4, S2-B4b-05, 50 Nanyang Avenue, Singapore 639798 (SG).

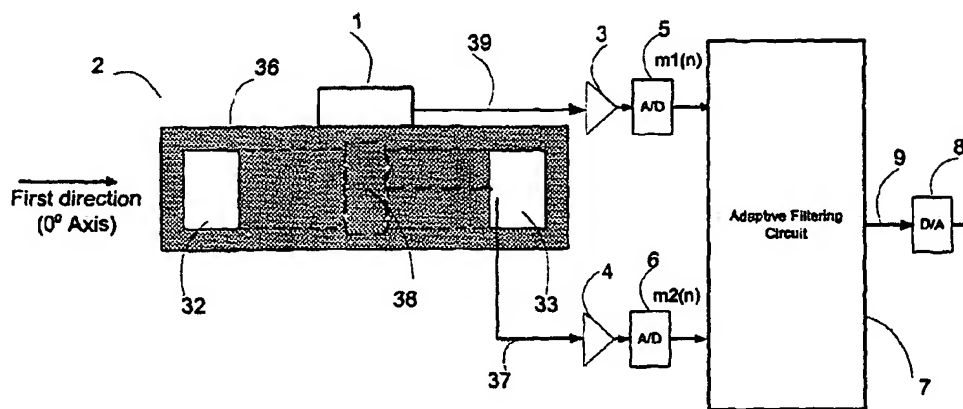
(74) Agents: NAMAZIE, Farah et al.; Haq & Namazie Partnership, Robinson Road, P.O. Box 765, Singapore 901515 (SG).

(81) Designated States (national): AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: ADAPTIVE DIRECTIONAL NOISE CANCELLING MICROPHONE SYSTEM



(57) Abstract: A known directional microphone, e.g. cardioid-type directional microphone, normally provides a directivity pattern which has higher gain at broad main beams (in the present invention, referred to as the first directions) and lower gain or even null at some other narrower beams (in the present invention, referred to as the second directions). The present invention provides a noise cancelling microphone system which comprises an omni-directional microphone (1), a normal (e.g., cardioid-type) directional microphone (2), preamplifiers (3, 4), analogue-to-digital (A/D) converters (5, 6), an adaptive filtering circuit (7), a digital-to-analogue (D/A) converter (8) and a case (11) specially designed for the system. The omni-directional microphone (1) can receive the sounds from any directions with a same or very similar gain. The directional microphone (2) can receive sounds from the first directions, except the second directions, with a similar gain. The two microphones are combined together with a closely acoustically-coupled way. In the applications of the present invention, the desired sound should be located at the second (or null) direction so that the system can output the desired sound with suppressed noise from other directions.

WO 01/95666 A2



Published:

— without international search report and to be republished
upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ADAPTIVE DIRECTIONAL NOISE CANCELING MICROPHONE SYSTEM**BACKGROUND AND PRIOR ART**

5

1. Field of the Invention

This invention relates to an adaptive directional noise canceling microphone system with high spatial selectivity and, more particularly, to an adaptive directional microphone system capable of canceling the undesired signals from the first directions and remaining the desired signal from the second directions, and to a hand-free high spatial selectivity microphone, such as for use with a computer voice input system, a hand-free communication voice input system, or the like.

2. Description of the Related Art

A directional microphone system is a microphone system having a directivity pattern. The directivity pattern describes the directional microphone system's sensitivity to sound pressure from different directions. It can provide higher gain at some wider areas in direction normally around the front direction (0°-axis) (in the present invention, referred to as the first directions) and lower gain or even null at some other directions normally around the back direction (referred to as the second directions in the present invention). The purpose of the directional microphone system is to receive sound pressure originating from a desirable sound source, such as speech, and attenuate sound pressure originating from undesirable sound sources, such as noise. The directional microphone system is typically used in noisy environments, such as a vehicle or a public place.

35

Directional microphones receiving a maximum amount of desired sound from a desired direction and meanwhile rejecting

undesired noise at a second or null direction, are generally well known in the prior art. Examples include cardioid-type directional microphones, such as cardioid, hyper-cardioid and super-cardioid directional microphones. However, those
5 microphones are of very broad main beam and very narrow null. In many applications such as computer voice input system or the like, a directional microphone system, which has a narrow main beam with much higher gain than that in the other directions, is required to acquire only the desired sound
10 from one direction and suppress the undesired noise from the any other directions.

One known technique for achieving directionality is through the use of a first-order-gradient (FOG) microphone element
15 which comprises a movable diaphragm with front and back surfaces enclosed within a capsule. The prior arts of directional microphones, such as in U.S. Patents US 4,742,548, US 5,121,426, US 5,226,076 and US 5,703,957, etc., only can provide a null with very low gain at certain narrow
20 directions but a beam with high gain at broad directions. In applications for such a microphone, the null of the microphone must be towards the undesired noise source and meanwhile the desired sound source should be positioned at the first directions of the microphone. However, in practice,
25 the arrangement is somewhat cumbersome because sometimes it is difficult to arrange the undesired noise source and desired sound source as above and moreover the noise may not come from a fixed direction. For example, there may be multiple noise sources from different directions or
30 distributed noise source.

SUMMARY OF THE INVENTION

35 It is accordingly an object of the present invention to provide an adaptive directional noise canceling microphone system that is of a narrow main beam with much higher gain

than other directions, that is, to provide an adaptive directional noise canceling microphone system to be able to achieve a good directivity pattern.

5 In order to achieve this object, the present invention provides an adaptive directional noise canceling microphone system with a very narrow main beam by integrating an omni-directional microphone and a normal directional microphone, such as cardioid-type directional microphone, together in a
10 closely acoustically-coupled way. Furthermore, it also provides a case specially designed for the microphone system to enhance its performance.

More specifically, it is an object of the invention to
15 provide a noise canceling microphone system which comprises an omni-directional microphone and a normal (e.g. cardioid-type) directional microphone, preamplifiers, A/D converters, a D/A converter, an adaptive filtering circuit and, additionally, a specially designed case.

20 Adaptive noise canceling filters are used to remain the desired signals from the second directions of the directional microphone and cancel the undesired signals from the first directions. A well-known technique for an adaptive noise
25 canceler proposed by Widrow et al., was described in an article entitled "Adaptive Noise Canceling: Principles and Applications", Proceedings of IEEE, vol.63, No.12, Dec. 1975.

Other objects, features and advantages according to the
30 present invention will be presented in the following detailed description of the illustrated embodiments when read in conjunction with the accompanying drawings.

FIG. 1 shows a perspective view of a directional microphone in the prior art;

FIG. 2 shows a top view of the directional microphone of FIG. 1;

FIG. 3 illustrates, in a table form, characteristics associated with a cardioid-type directional microphone for different values of B in the prior art;

FIG. 4 shows a combination of a top view and a structure diagram;

FIG. 5 shows a perspective view of the present invention for the example of using a cardioid directional microphone (Column "CARDIOID" in Figure 3);

FIG. 6 illustrates a structure diagram of an embodiment of the present invention for the example of using a cardioid directional microphone;

FIG. 7 and 8 illustrate schematic diagrams of adaptive filtering circuits within said embodiment;

FIG. 9 illustrates a case structure specially designed for the directional microphone in the present invention for the example of using a cardioid directional microphone.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

FIG. 1 shows a perspective view of a directional microphone apparatus in the prior art of U.S. Patent 5,226,076. The directional microphone apparatus 2 has a housing 36 for a FOG microphone element 38 that effectively extends the distance (we refer it to d hereafter) between sound ports of the FOG

microphone element 38 contained therein. The housing 36 is made from an acoustically opaque material which does not transmit sound pressure as efficiently as air. However, the housing includes openings 32 and 33 which admit sound pressure, via acoustically transparent channels 34 and 35, into the cavity where the microphone element 38 resides. Microphone element 38 includes a pair of wires 37. The housing 36 is sized to form a seal with the microphone element 38 so that the sound pressure in one of the channels (e.g., 34) is not leaked to the other channel (e.g., 35) around the microphone element 38.

FIG. 2 is a top view of said directional microphone apparatus 2 that illustrates its general shape. The first directions are normally referred to a broad area around the front direction in the FIG. 1 and FIG. 2.

Generally, the directivity pattern $D(\hat{E})$ associated with FOG and cardioid-type microphones operating in far field, and where $kd < 1$, is given by the following equation:

$$D(\hat{E}) = \frac{1 + B \cdot \cos(\hat{E})}{1 + B}, \quad (1)$$

where $k = 2\pi f/c$, d is the difference between said two sound ports of a directional microphone system, \hat{E} is a polar orientation of the improving wavefront with respect to the major axis of the microphone, c is the wave velocity, f is the frequency of sound, $B = (d/c)/(R_a C_a)$, C_a is acoustic compliance (similar to capacitance) and R_a is acoustic resistance. The parameter B alters the directivity pattern.

FIG. 3, which is also shown and described in US-A 5,121,426 and in US-A 5,226,076 (said descriptions are incorporated herewith by references) illustrates the directivity pattern associated with the cardioid-type microphones for different values of B . Each one in this table has its own set of

characteristics such as 1) the direction of its null; 2) distance factor; and 3) front-to-back response ratio, etc. When $B = 1$, the directivity pattern is cardioid, which has a very broad main beam, a null at 180° and infinite front-to-back response ratio.

An omni-directional microphone can receive sounds from any directions with a same similar gain, but a FOG or cardioid-type directional microphone can receive sounds from any directions with a similar gain except the null or second directions. Ideally the cardioid-type directional microphone can not receive any sounds from the null directions or can receive sounds with much lower gains from second directions. If an omni-directional microphone is adhered to a cardioid-type directional microphone in closely acoustically-coupled way and a proper adaptive filtering circuit is applied, only sounds from the null or second directions will be remained and the sounds from the any other directions will be canceled. Here closely acoustically-coupled way means that the acoustic signals received by the two microphones are fully or highly correlated each other.

FIG. 4 illustrates a combination of a top view on a case 36 for an omni-directional microphones 1, said directional microphone 2 and the structure diagram of the present invention. The sounds received by the omni-directional microphone 1 are amplified by a first preamplifier 3 and then converted to a first digital signal $m_1(n)$ by a first A/D converter 5. The sounds received by said directional microphone 2 are amplified by a second preamplifier 4 and then converted to a second digital signal $m_2(n)$ by a second A/D converter 6. Both of said digital signals $m_1(n)$ and $m_2(n)$ are sent to an adaptive filtering circuit 7. The result signal after processing is outputted at the output 9 through a D/A converter 8. If a sound comes from the second direction, the omni-directional microphone 1 can receive it with a quite high gain, but said directional microphone 2 can

not receive it or only can receive it with a much lower gain. On the other hand, if the same sound comes from any other directions, both the microphones 1 and 2 can receive it with similar gains and moreover the received signals from both microphones 1, 2 are highly correlated. So when a desired sound comes from the second direction and meanwhile undesired sounds come from the other directions, the undesired sounds can be canceled and the desired sound can be remained by said adaptive filtering circuit 7 in the noise canceling microphone system in the present invention.

It was found that when sounds only come from the first directions, said digital signals $m1(n)$ and $m2(n)$ are highly correlated to each other. On the other hand, they are only weakly correlated when the same sounds only come from the second directions. In addition, for said directional microphone 2, the gain of the first directions is much higher than that of the second directions. Using the information above, said adaptive filtering circuit 7 cancels the component in said first digital signal $m1(n)$, the digital signal from said omni-directional microphone 1, due to the sounds coming from the first directions and remains the component in said first digital signal $m1(n)$ due to the sounds coming from the second directions while said second digital signal $m2(n)$, the digital signal from said directional microphone 2, is used as a reference signal.

FIG. 5 illustrates an example that said directional microphone 2 is a cardioid directional microphone as described in Column "CARDIOID" in Figure 3. An adaptive directional noise canceling microphone system according to the present invention includes an omni-directional microphone 1 with a directivity pattern 21 and a cardioid directional microphone 2 with a directivity pattern 22. Said two microphones 1 and 2 are adhered to each other in a closely acoustically-coupled way. There are two (pairs of) wires 23

and 24 to capture the signals from the two microphones 1 and 2, respectively.

FIG. 6 illustrates the structure diagram of an embodiment of the present invention for the example of Figure 5. Said omni-directional microphone 1 is adhered to said directional microphone 2. The sounds received by said omni-directional microphone 1 are amplified by said first preamplifier 3 and then converted to said first digital signal $m1(n)$ by said first A/D converter 5. The sounds received by said cardioid directional microphone 2 are amplified by said second preamplifier 4 and then converted to said second digital signal $m2(n)$ by said second A/D converter 6. Both of said digital signals $m1(n)$ and $m2(n)$ are sent to said adaptive filtering circuit 7. The result signal after processing is outputted at the output 9 through said D/A converter 8. If a sound comes from the null direction (180°), said omni-directional microphone 1 can receive it with a quite high gain, but said cardioid directional microphone 2 can not receive it or only can receive it with a very low gain. On the other hand, if the same sound comes from any other directions, both said microphones 1 and 2 can receive it with similar gains and moreover the received signals from both microphones 1, 2 are highly correlated. So when a desired sound comes from the null direction and meanwhile undesired sounds come from the other directions, the undesired sounds can be canceled and the desired sound can be remained by said adaptive filtering circuit 7 in the noise canceling microphone system in the present invention.

30

FIG. 7 illustrates a scheme for the operation of said adaptive filtering circuit 7, associated with said omni-directional microphone 1 and said directional microphone 2 as a first embodiment of said adaptive filtering circuit 7. Said first digital signal $m1(n)$ is delayed a predetermined number of ($\Delta \geq 0$) samples by a delay circuit 73 to generate a delayed signal $m1(n - \Delta)$. Said adaptive filter 71 is used to

35

estimate the component in said delayed signal $m1(n-)$ due to the sounds coming from the first directions and outputs said filter output signal $y1(n)$. Said delayed signal $m1(n-)$ is subtracted by said filter output signal $y1(n)$ at said adder 5 72 to get said error signal $e1(n)$. Said adaptive filter 71 receives said second digital signal $m2(n)$ as reference signal and said error signal $e1(n)$ to update its coefficient based on said step size $u1$. Said error signal $e1(n)$ is outputted as a result of this operation. If said second digital signal 10 $m2(n)$ contains only the component due to the sounds coming from the first directions, the scheme can provide a good result. However, in practice, while said second digital signal $m2(n)$ contains mainly the component due to the sounds coming from the first directions, it also may contain the 15 component due to the sounds coming from the second directions. In this case, the performance of this scheme could be degraded.

FIG. 8 illustrates another scheme for the operation of said 20 adaptive filtering circuit 7, in which cross-talk adaptive filters 71, 74 are used. Said first digital signal $m1(n)$ is delayed ($\Delta \geq 0$) samples by said delay circuit 73 to generate said delayed signal $m1(n-)$. Said adaptive filter 71 is used to estimate the component in said delayed signal 25 $m1(n-)$ due to the sounds coming from the first directions while an additional adaptive filter 74 is used to estimate the component in said second digital signal $m2(n)$ due to the sounds coming from the second directions. Said delayed signal $m1(n-)$ is subtracted by said filter output signal $y1(n)$ of 30 said (first) adaptive filter 71 at said adder 72 to get said error signal $e1(n)$. Said second digital signal $m2(n)$ is subtracted by an additional filter output signal $y2(n)$ of said additional adaptive filter 74 at an additional adder 75 to get an additional error signal $e2(n)$. Said first adaptive 35 filter 71 uses said additional error signal $e2(n)$ as its reference, said first error signal $e1(n)$ as its error signal and $u1$ as its step size to update its coefficients.

10

Similarly, said additional adaptive filter 74 uses said (first) error signal $e_1(n)$ as its reference, said additional error signal $e_2(n)$ as its error signal and u_2 as its step size to update its coefficients. Said step sizes u_1 and u_2 can be fixed or variable. After said adaptive filters 71 and 74 converge, said adaptive filter 71 can estimate the component in said delayed signal $m_1(n-)$ due to the sounds coming from the first directions and said adaptive filter 74 can estimate the component in said second digital signal $m_2(n)$ due to the sounds coming from the second directions. As a result, said (first) error signal $e_1(n)$ is the signal coming from the second directions which suppresses the sounds coming from the first directions and which is outputted as the result of said adaptive filter circuit 7.

15

FIG. 9 illustrates a case designed for the noise canceling microphone system for the example of Figure 5. The case 11 is a rectangular or cylindric box. In the design, the outer surface 12 of the case 11 is made of acoustically shielded material to prevent the sounds from going through. There are two openings 13 and 14 at the two ends of the case 11 which admit sounds via acoustically transparent channels 15 and 16, into cavity where said two microphones 1 and 2 reside together. A seal 17 is formed with said two microphones 1 and 2 by acoustically shielded material so that the sound in the channel 15 is not leaked to the channel 16 or vice versa. The design of the case 11 allows the sounds from around the front to arrive at said two microphones 1, 2 from the direct front (0°) and the sounds from around the back to arrive at said two microphones 1, 2 from the null direction (180°).

In the practical applications, the desired sound should be located at the second (or null) direction as closely as possible so that the output of the noise canceling microphone system can remain the desired sound and suppress the undesired sounds from any other directions.

35

11

CLAIMS

What is claimed is:

- 5 1. An adaptive directional noise canceling microphone system comprising:
- an omni-directional microphone (1) for receiving sounds from any direction with a same or very similar gain;
 - a directional microphone (2), which has a very broad main
10 beam with higher gain and a narrow beam with lower or even null gain at the second directions, for receiving sounds from the main beam and rejecting or suppressing the sounds from the beam at the second directions; and
 - said microphones (1, 2) being arranged in a closely
15 acoustically-coupled way.
2. The adaptive directional noise canceling microphone system according to claim 1, wherein the directional microphone (2) is a first-order
20 gradient (FOG) directional microphone or a cardioid directional microphone or the like.
3. The adaptive directional noise canceling microphone system according to claim 1 or 2, further comprising:
- 25 • a signal output (9) for providing a result signal;
 - an adaptive filtering circuit (7) for receiving first and second digital signals $m_1(n)$, $m_2(n)$ originating from said microphones (1, 2), and estimating the desired signal to thereby outputting it as said result signal.
30
4. The adaptive directional noise canceling microphone system according to claim 3, further comprising:
- first and second preamplifiers (3, 4) for receiving and
35 amplifying signals resulting from sounds received by said microphones (1, 2); and

- first and second A/D converters (5, 6) receiving said received and amplified signals and outputting said first and second digital signals ($m_1(n)$, $m_2(n)$).

5 5. The adaptive directional noise canceling microphone system according to claim 3 or 4,
wherein said adaptive filtering circuit (7) comprises an adaptive filter (71) and an adder (72), said adaptive filter (71) being inputted by said second digital signal ($m_2(n)$), by
10 a step size signal (u_1) and by an error signal ($e_1(n)$) and outputting a filter output signal ($y_1(n)$), said adder (72) being inputted by said first digital signal ($m_1(n)$) and by said filter output signal ($y_1(n)$) and outputting said error signal ($e_1(n)$) as said result signal of said adaptive
15 filtering circuit (7).

6. The adaptive directional noise canceling microphone system according to claim 5,
further comprising a delay circuit (73) being inputted by
20 said first digital signal ($m_1(n)$) providing a delayed digital signal ($m_1(n-\Delta)$) ($\Delta \geq 0$) as an input signal for said adder (72) instead of said first digital signal ($m_1(n)$).

7. The adaptive directional noise canceling microphone system
25 according to claim 5 or 6,

- further comprising an additional adaptive filter circuit (74) and an additional adder (75), said additional adder (75) being arranged between said second digital signal ($m_2(n)$) as its input signal and said adaptive filter (71);
30
- said additional adder (75) providing an additional error signal ($e_2(n)$) at its output, which is fed to both of said adaptive filter circuits (71, 74), and receiving an additional filter output signal ($y_2(n)$) provided by said
35 additional adaptive filter circuit (74).

13

8. The adaptive directional noise canceling microphone system according to any of the claims 3 to 7, wherein each of said adaptive filter circuits (71, 74) further comprise an input for a respective step size signal (u1, u2).

9. An adaptive directional noise canceling microphone system comprising:

- a directional microphone (2), which has a higher gain at one or more first directions and a lower gain even null at one or more second directions, for receiving sounds coming from said first directions and second directions;
- an omni-directional microphone (1), which is adhered to said directional microphone (2) in a closely acoustically coupled way, for receiving the same sounds from any directions;
- a signal output (9) for providing a result signal;
- an adaptive filtering circuit (7) for processing digital signals (m1(n), m2(n)) acquired by said two microphones (1, 2), delaying that one (m1(n)) of said digital signals (m1(n), m2(n)) from said omni-directional microphone (1) for a number of predetermined samples by a delay circuit (73) and estimating the desired signal as an error signal (e1(n)) to thereby output it to the signal output.

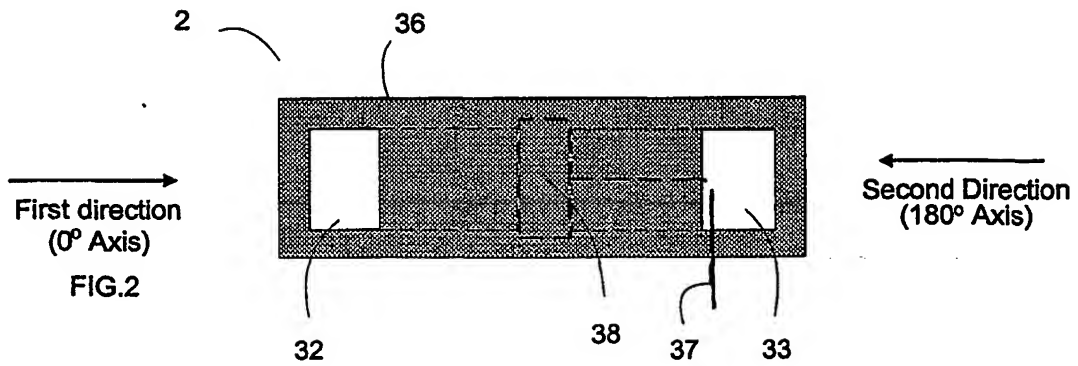
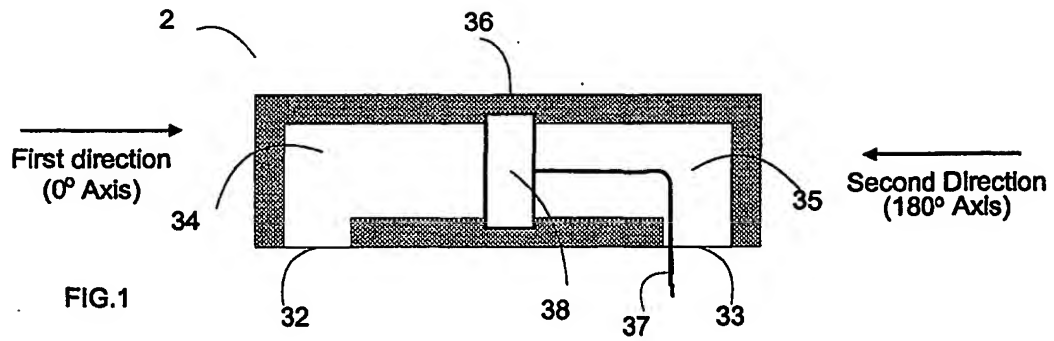
10. The adaptive directional noise canceling microphone system according to any of the preceding claims, further comprising a case (11) specially designed for the noise canceling microphone system for allowing the sounds from around the front to arrive at said two microphones (1, 2) from the direct front direction (0°) and the sounds from around the back to arrive at said two microphones (1, 2) from the null direction.

11. The adaptive directional noise canceling microphone system according to claim 10,

14

wherein said case (11) comprises two acoustically transparent channels (15, 16) adjacent to each other, but acoustically isolated from each other, whereby said two microphones (1, 2) are arranged between said two acoustically transparent
5 channels (15, 16), surrounded by a seal (17) acoustically shielding said two acoustically transparent channels (15, 16) from each other.

12. The adaptive directional noise canceling microphone
10 system according to claim 10 or 11,
wherein an outer surface of said case (11) is of an acoustically shielding material.



Directivity pattern of cardioid-type directional microphone

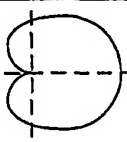
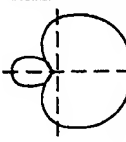
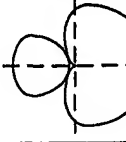
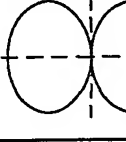
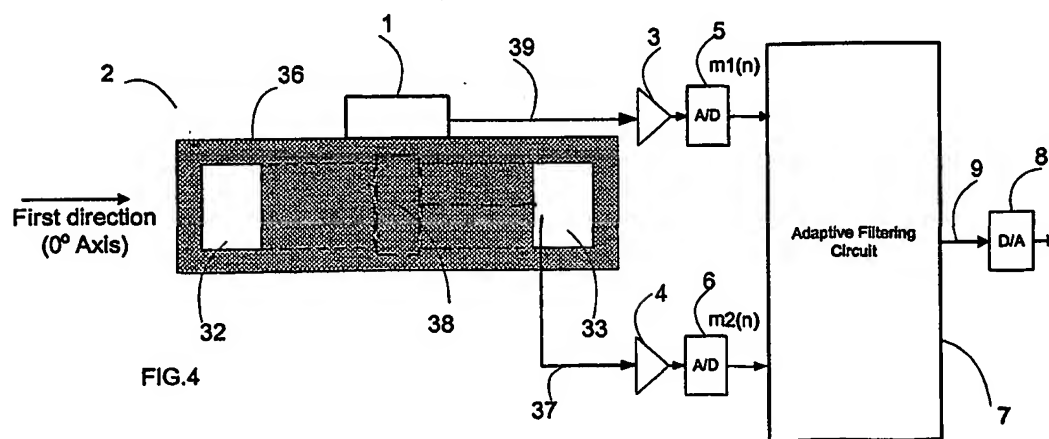
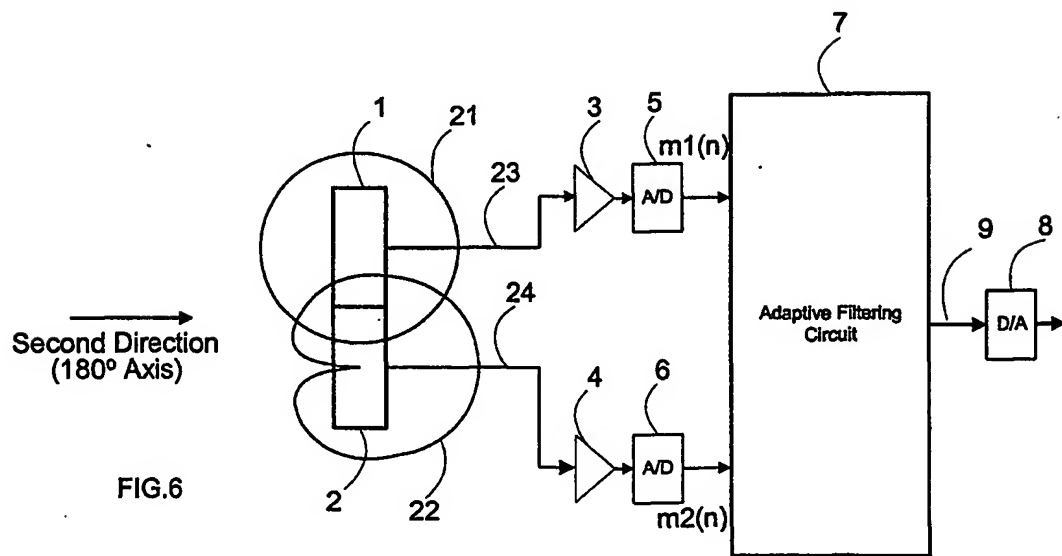
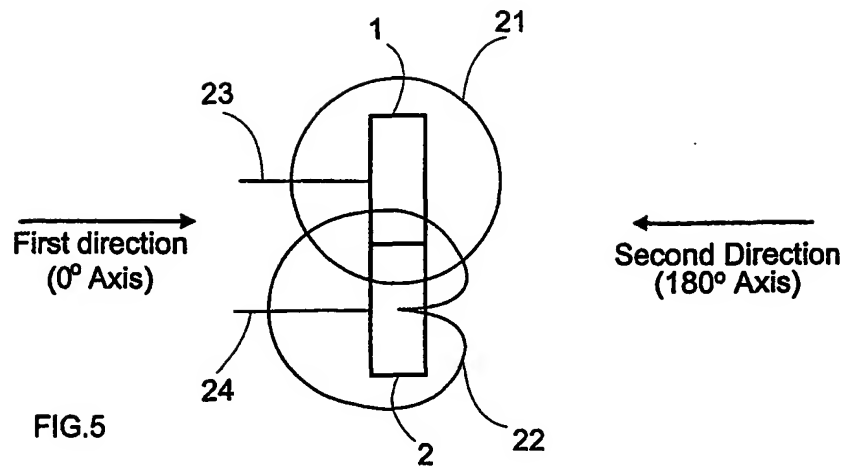
ACTERISTIC	CARDIOID	SUPERCARDIOID	HYPERCARDIOID	BIDIRECTIONAL
POLAR RESPONSE PATTERN				
B	1	$\sqrt{3}$	3	∞
PORLAR DIRECTIVITY $D(\theta) = \frac{1+B\cos\theta}{1+B}$	$\frac{1+\cos\theta}{2}$	$\frac{1+\sqrt{3}\cos\theta}{1+\sqrt{3}}$	$\frac{1+3\cos\theta}{4}$	$\cos\theta$
BEAM WIDTH 6dB DOWN	131°	115°	105°	90°
FRONT-TO-BACK RESPONSE RATIO	180°	156°	141°	120°
RANDOM ENERGY EFFICIENCY	∞	3.73 11.4dB	2.00 6.0dB	1.00 0dB
RANDOM ENERGY EFFICIENCY	0.333 -4.8dB	0.268 -5.7dB	0.250 -6.0dB	0.333 -4.8dB
DISTANCE FACTOR	1.73	1.93	2.00	1.73
NULL	180°	$\pm 125^\circ$	$\pm 110^\circ$	$\pm 90^\circ$

Figure 3





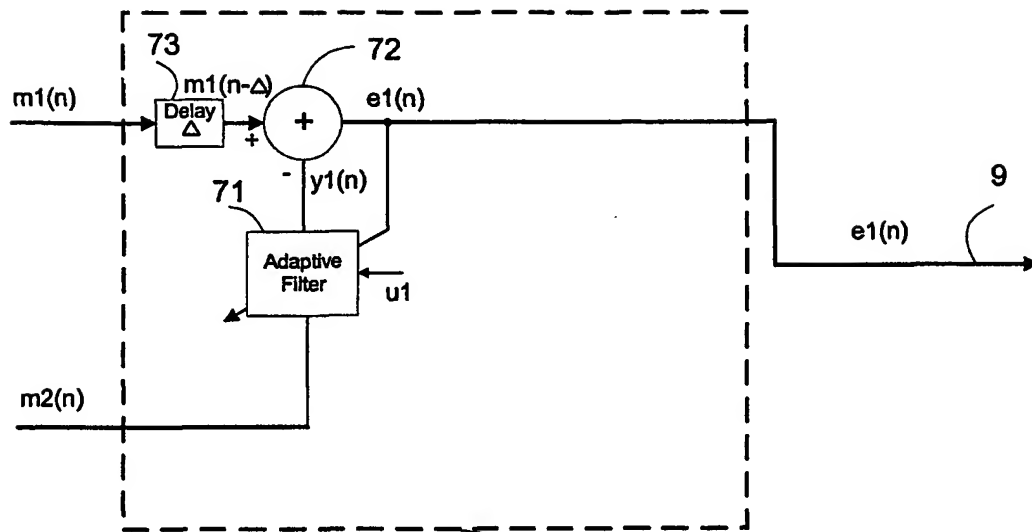


FIG. 7

7

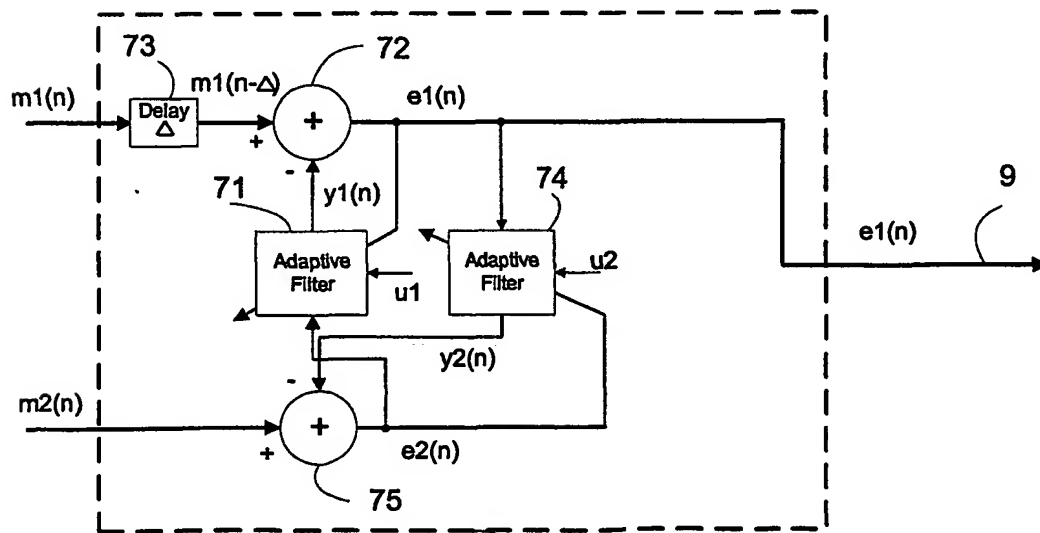


FIG. 8

11

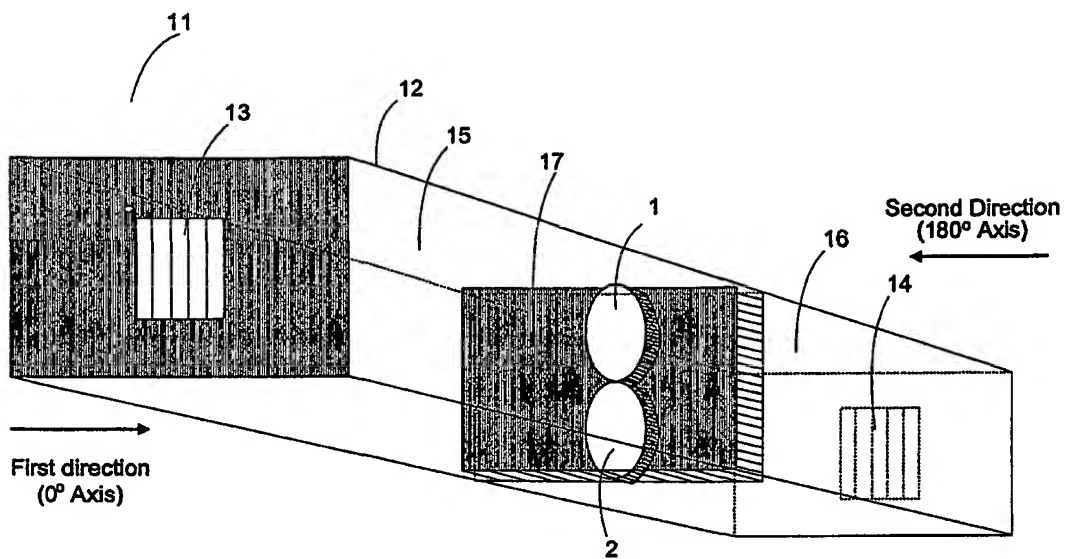


FIG.9